

# **Portable Soft X-ray Diagnostics for Transformative Fusion-Energy Concepts**

**DE-FOA-0001953-1604**

**Fusion Diagnostics Program Review (Virtual)  
March 5, 2021**

Glen Wurden (LANL)

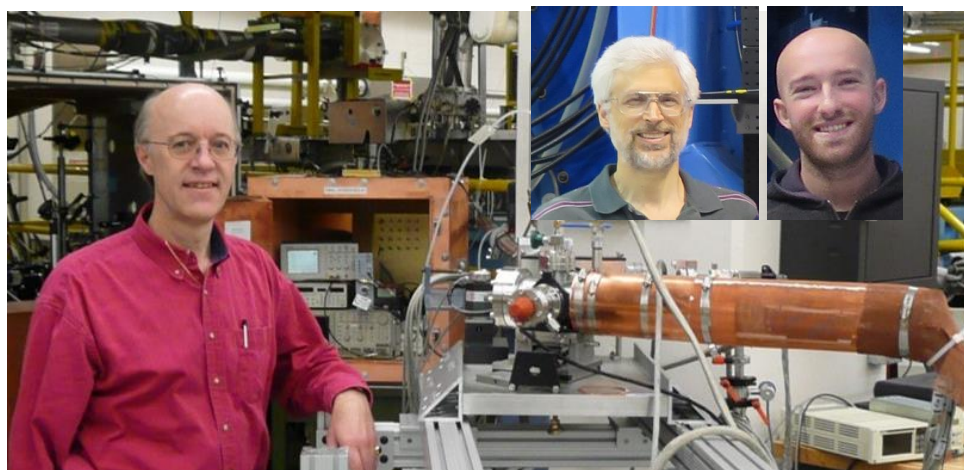
Bruno Bauer (UNR)



U.S. DEPARTMENT OF  
**ENERGY**

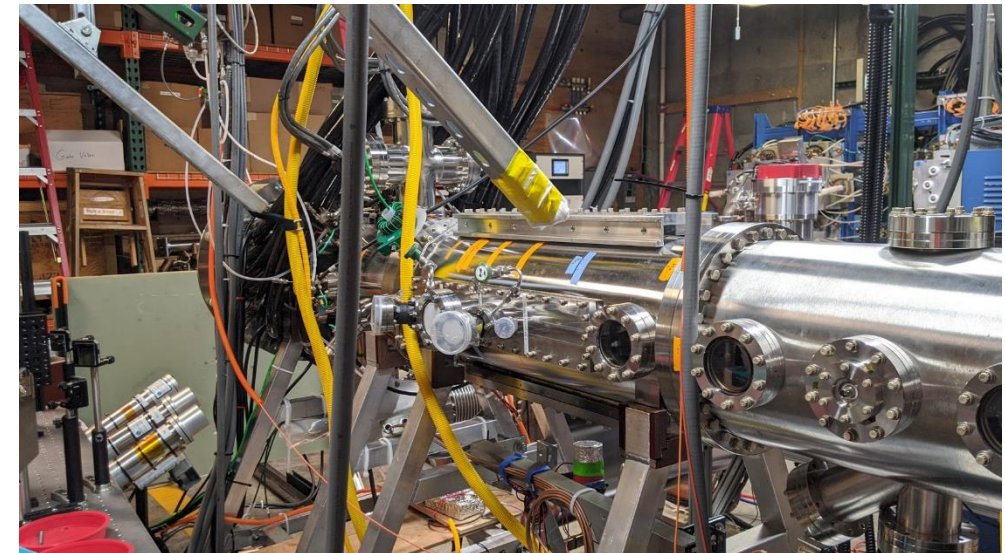
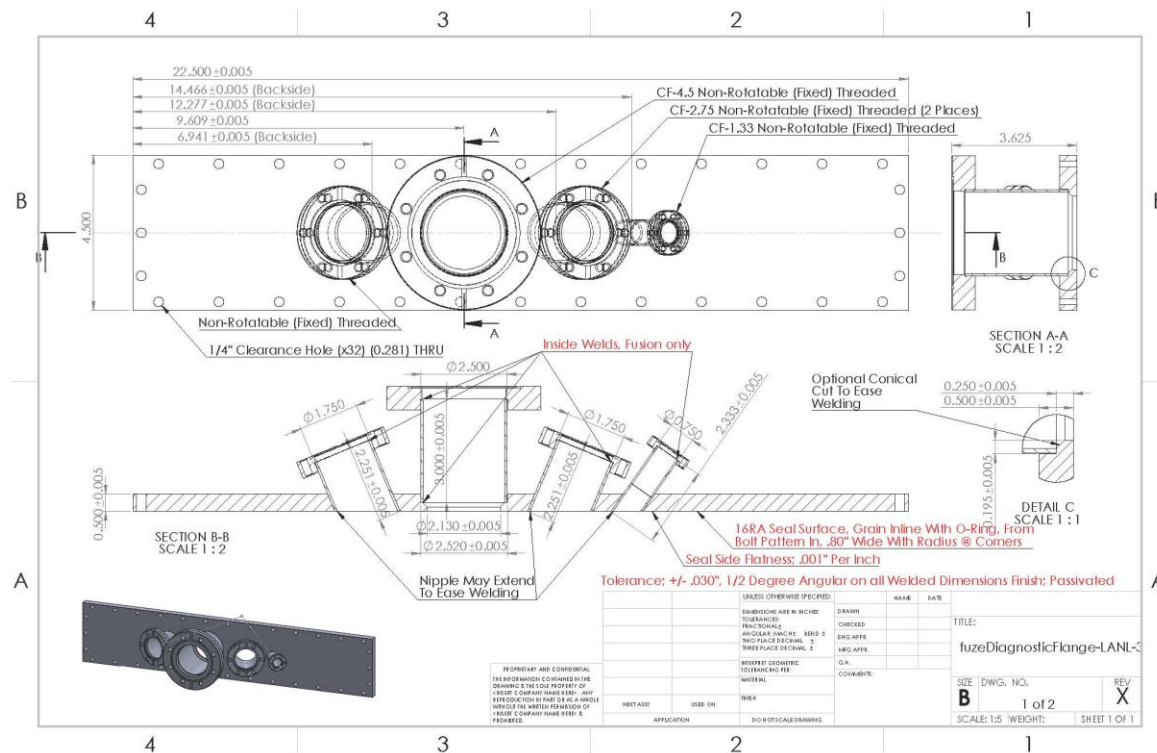
# Team members and roles

- ▶ Glen Wurden, project leader
- ▶ Tom Weber, LANL staff scientist
- ▶ Prof. Bruno Bauer, UNR lead
- ▶ Stephan Fuelling, UNR scientist
- ▶ Aidan Klemmer, UNR grad student
- ▶ UNR will be fielding an extreme ultraviolet (EUV) McPherson 310 gated spectrometer system to Zap Energy, but setup and calibration work at UNR has been delayed due to Covid restrictions.



- ▶ LANL has fielded filtered soft x-ray PMT units (four), along with an x-ray ratio analysis code. (100 eV- 5 keV range)
- ▶ LANL has fielded a fast soft x-ray pinhole camera imager at FuZE in Seattle. (8 um Be filter)
- ▶ LANL shipped two acquisition cameras in use at FuZE..... A 12-frame Hadland intensified camera, at up to 200 million frames/second, and a single frame, but extremely sensitive 5- Megapixel PCO C1 intensified imager.
- ▶ LANL shipped filters, pressure gauges, control computer, and specialized vacuum flange hardware for FuZE.
- ▶ Initial experiments were conducted between Aug-Dec 2020, with nearly daily LANL participation via Zoom.

## LANL is providing vacuum soft x-ray instruments for FuZE



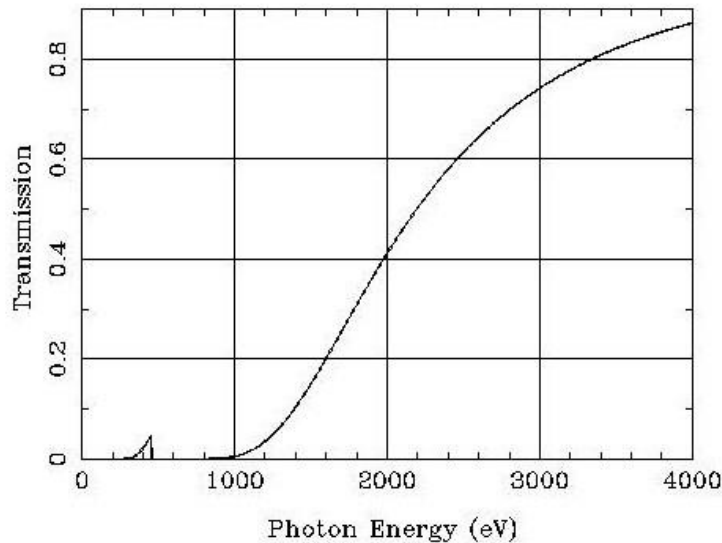
Designed at LANL, drawn up at UNR, built at LANL off-site shop, just before Covid restrictions hit. Assembled with windows and foils, leak checked, and shipped on Aug 6, 2020. Installed on FuZE on Aug 11, 2020.

# Example foil transmission for soft x-rays

We are particularly interested in photons in the  $\sim 1\text{keV}$  range

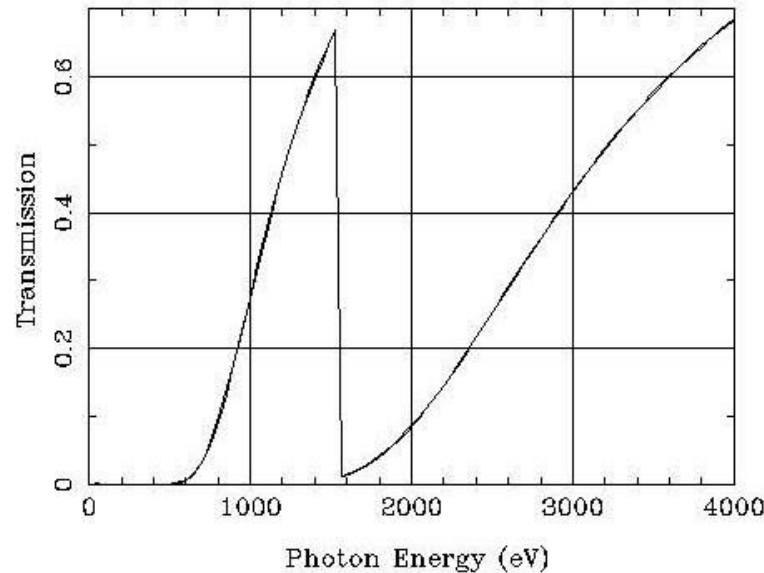
**Filter Transmission**

Ti Density=4.54 Thickness=2. microns



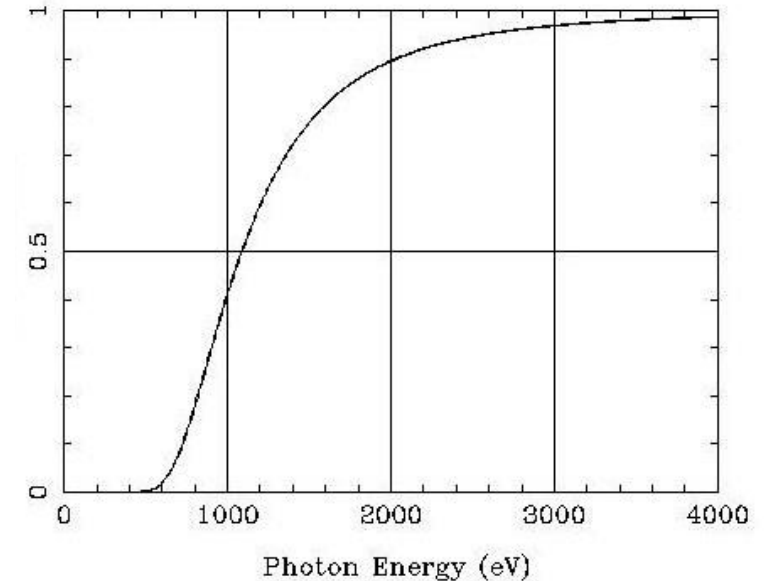
**Filter Transmission**

Al Density=2.6989 Thickness=4. microns



**Filter Transmission**

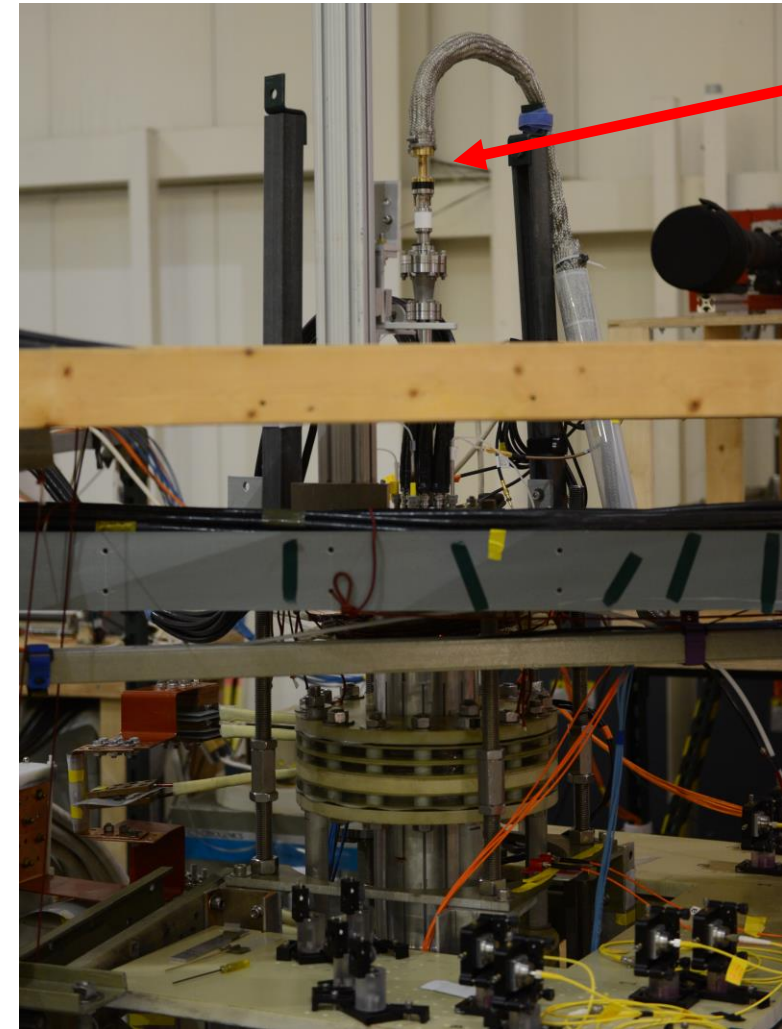
Be Density=1.848 Thickness=8. microns



# In the past, we have deployed soft x-ray instruments on a variety of experiments

- ▶ LANL has used x-ray diagnostics for decades, on platforms ranging from underground tests, to satellites, to accelerators, and to laboratory laser and magnetic fusion experiments.
- ▶ In field reversed configuration (FRC) experiments, we have faced particularly noisy electromagnetic environments, and have proven techniques for robust noise reduction to enable detection of low-level signals.
- ▶ We also fielded a multi-frame fast soft x-ray pinhole camera at our implosion magnetized target fusion experiment on FRCHX.

Wurden & Coffey, Review of Scientific Instruments **83**, 10E516 (2012); <https://doi.org/10.1063/1.4733536>



A shielded seven channel XUV diode detector can be seen on top of the FRCHX experiment at AFRL in 2013 <sup>4</sup>

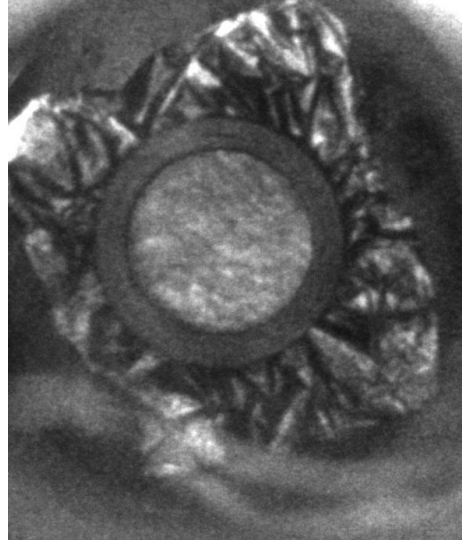
# Multi-frame Hadland Ultra 24 fast 1 Megapixel camera

- ▶ 12 independently gated intensified images are possible with the Hadland camera. Intensified, 12-bit dynamic range, up to 200 Million fps. It is shown here with a fast 200 mm f/2 Nikon lens. It is controlled by a PC over fiber-optic ethernet.
  - ▶ We pulled it off of the PLX experiment where it was most recently in use.
  - ▶ This camera was originally procured via Obama stimulus monies in 2009.
  - ▶ It will be the acquisition system for the x-ray imager, viewing visible light given off by the P47 phosphor, in response to x-rays that make it through the foil in the pinhole snout.
- 
- ▶ We also deployed a 5 Mpixel, extremely sensitive PCO C1 intensified visible camera, but it only records one frame on FuZE timescales.



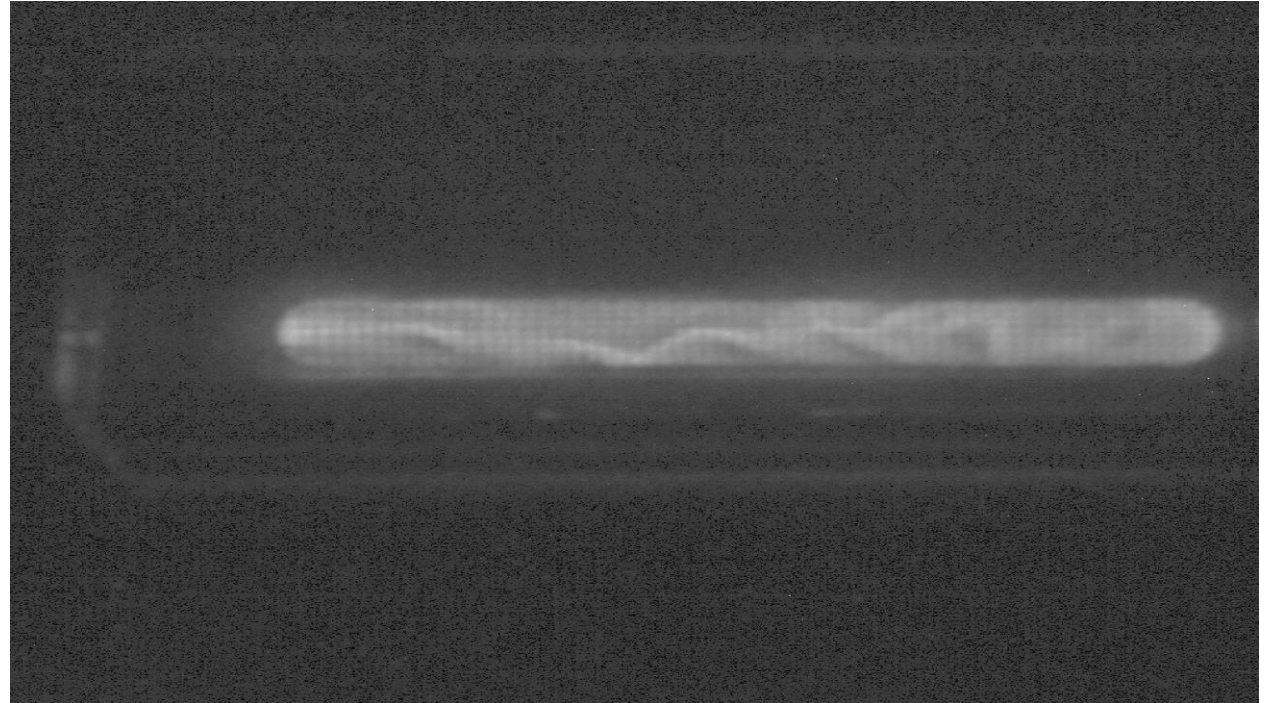
# We are running experiments remotely (via Zoom) with multiple instruments at Zap Energy Inc.'s FuZE machine in Seattle

- ▶ We found that the hot expanding gas from FuZE full energy thyristor bank shots would break our 4  $\mu\text{m}$  Al foils behind a 5/16" aperture on the PMT instruments in a single pulse. To get some measurements with the four PMT/phosphor detectors, we used a lower energy, non-optimized shorter current waveform ignitron bank, and thicker 7  $\mu\text{m}$  and 12  $\mu\text{m}$  foils.
- ▶ Vacuum pinhole snout for the pinhole imager, with 2 mm aperture. We used an 8  $\mu\text{m}$  Be foil, without any damage issues.



# Initial experiments at FuZE

- ▶ At first we struggled, caught between needing big enough signals to beat electrical noise issues, but also encountering nonlinear phototube response above a certain point.
- ▶ Combined with also not realizing at first when our foils were breaking. (We had to use ND filters to reduce phosphor light to the PMT's, even at low HV settings.)
- ▶ Finally, we went to a hard EMP enclosure with battery powered scope and HV supplies, with good braid from the PMTs to the shielding box, which solved the EMP problems. Then we also used an operating regime where the foils weren't getting blown out, which lead to good combined data runs in Dec 2020.
- ▶ Visible movies of the snaking (non-optimized) plasma pinch column were also enlightening. The plasma is a difficult target for any instrument with a "small" field of view.



A single 100 nsec visible light image of a FuZE plasma taken from the bottom of the experiment through a long window. The transverse dimension of the pinch is 3-6 mm. These conditions are somewhat "non-optimized" with a new ignitron bank.

# Future plans

- ▶ Zap is relocating their experiment to an off-campus facility
- ▶ We will make combined visible/x-ray/neutron measurements at the new experiment later in 2021.
- ▶ Due to motion of the plasma column, “simple” x-ray ratios to determine the central electron temperature have to be combined with knowledge of the pinch position. We may try a 7-channel x-ray diode measurement from one side of the machine, as we have measured adequate x-ray signals through 7 and 12  $\mu\text{m}$  Al foils.
- ▶ Our BETHE project will use a X-Spectrum 352 frame 4.5 MHz solid-state x-ray imager in a pinhole camera configuration.
- ▶ We are writing an INFUSE proposal with TAE, on related x-ray diagnostics.



An XUV-7 instrument, with 1  $\text{mm}^2$  x-ray diodes.



X-Spectrum multi-frame solid-state soft x-ray detector